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(56) Documents cited GB 1596298
(58) Field of search G1N

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(54) **Respiration monitor**

(57) Apparatus for monitoring the respiration of subjects, particularly hospital patients or infants, includes an inductive coil of insulated wire mounted on elasticated tape 12, the tape being sewn or threaded in channels 13 on a garment 14 as a single length in alternating rows, arranged so that in use the coil comprises a plurality of turns encircling the body, each turn being wound in the opposite sense to the preceding turn, and the garment may be opened completely without breaking any electrical connections. The coil may form an inductive element in a variable frequency oscillator, frequency changes in which can be processed electronically to provide continuous information of the respiratory parameters. In an embodiment particularly suitable for use with infants, the coil may form a radiative element in a

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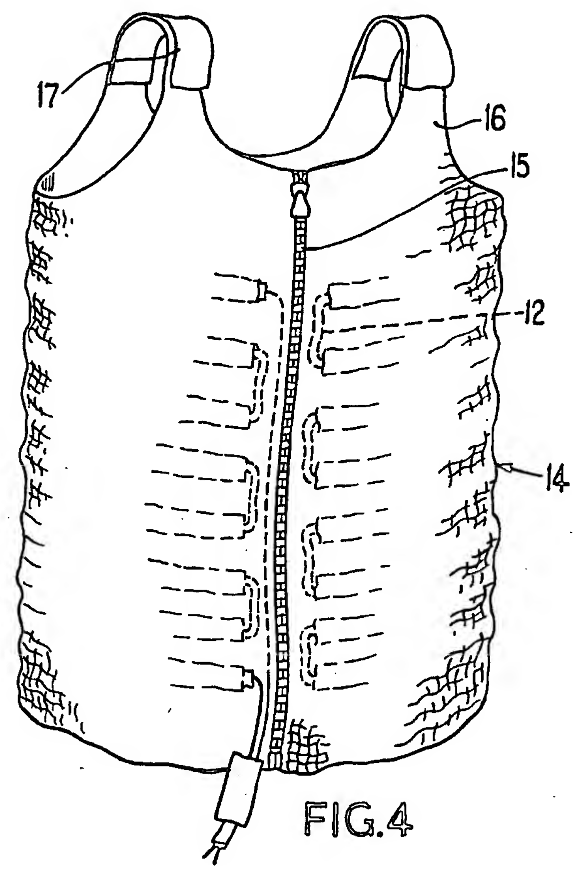

FIG.4

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

battery-powered oscillator isolated from the remainder of the monitor circuit. The radiation is detected and transmitted to the circuit by an aerial which may be conveniently placed under a cot mattres.

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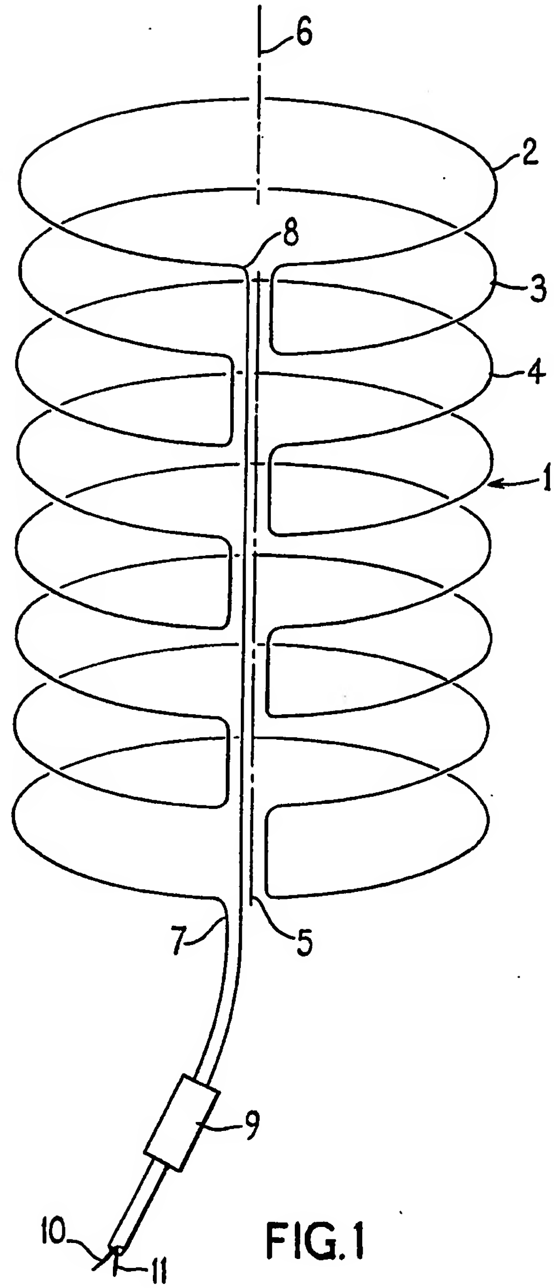


FIG.1

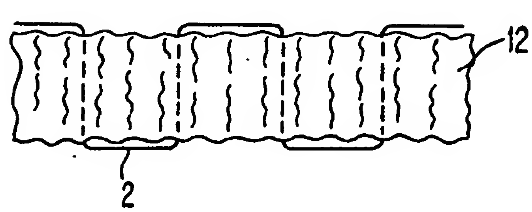


FIG. 2

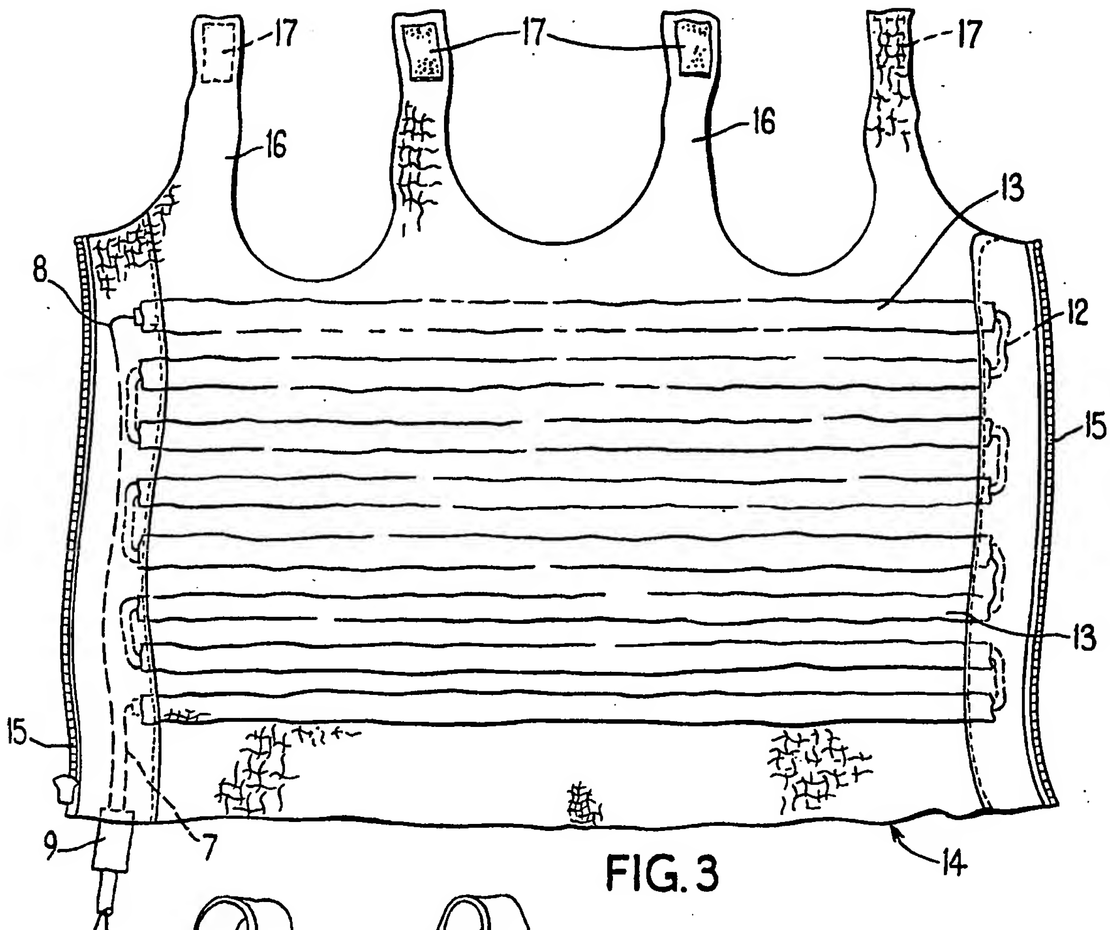


FIG. 3

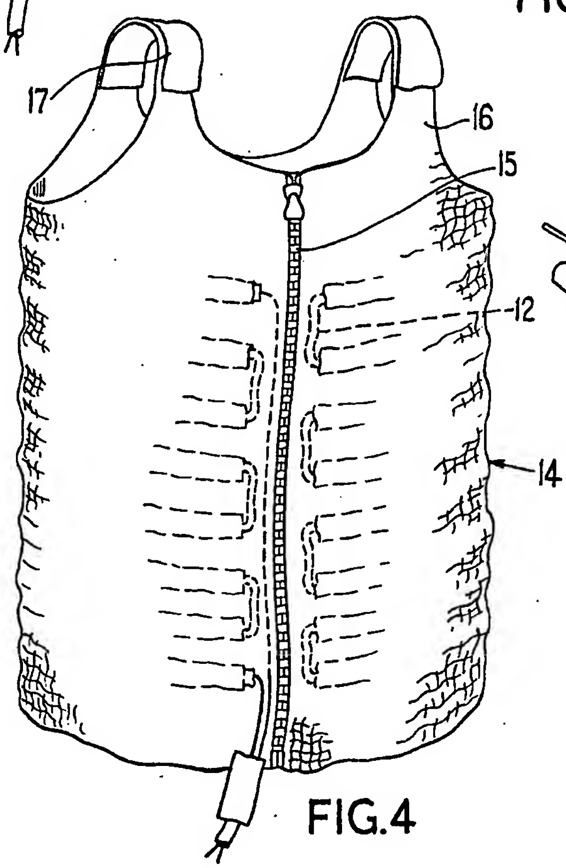


FIG.4

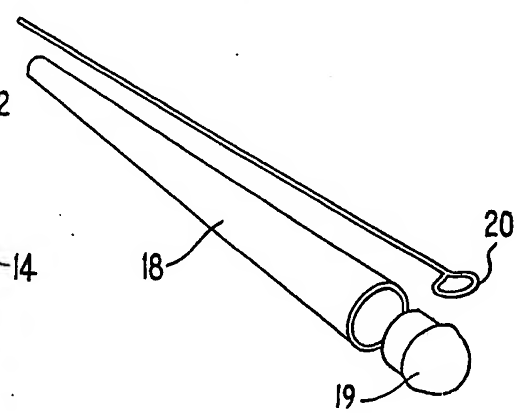
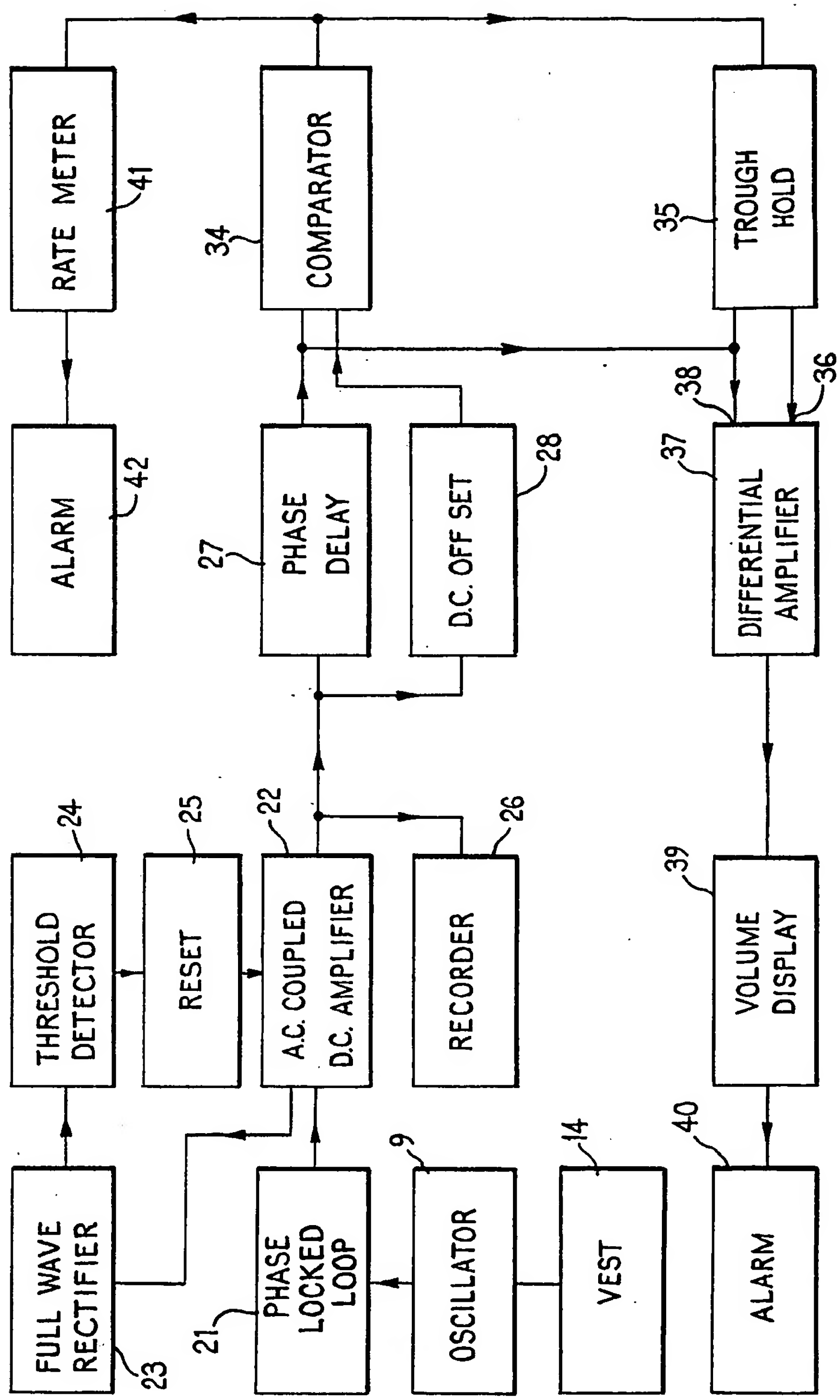


FIG.5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41
ALARM
42
COMPARATOR
34
PHASE DELAY
27
D.C. OFF SET
28
TROUGH HOLD
35
DIFFERENTIAL AMPLIFIER
37
38
36
THRESHOLD DETECTOR
24
RESET
25
A.C. COUPLED D.C. AMPLIFIER
22
RECORDER
26
VOLUME DISPLAY
39
FULL WAVE RECTIFIER
23
PHASE LOCKED LOOP
21
OSCILLATOR
9
VEST
14
ALARM
40

FIG.6

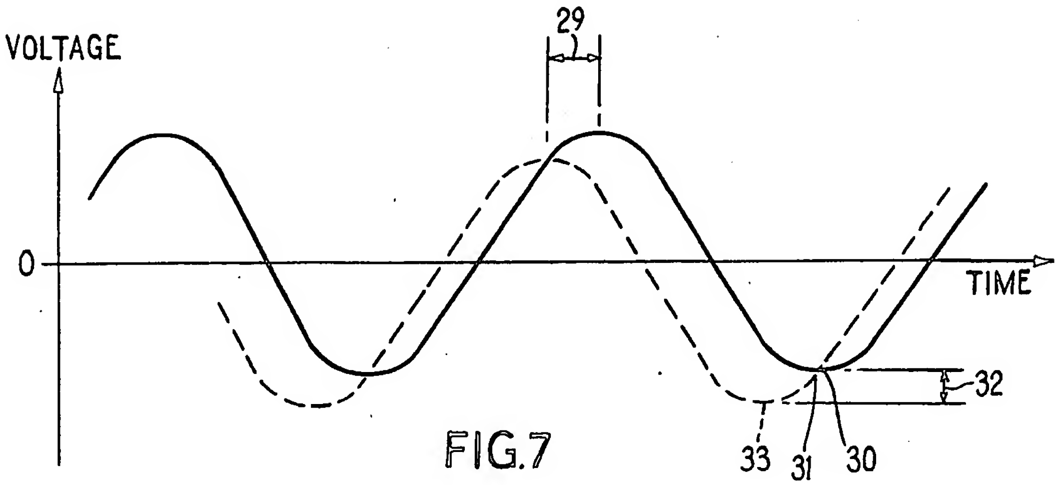
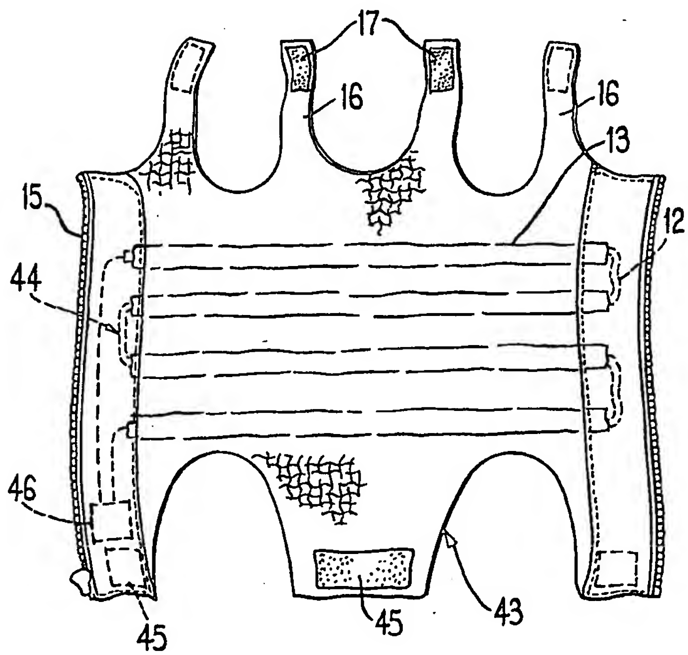


FIG.7



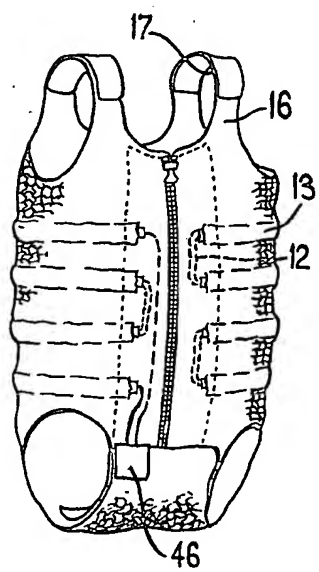
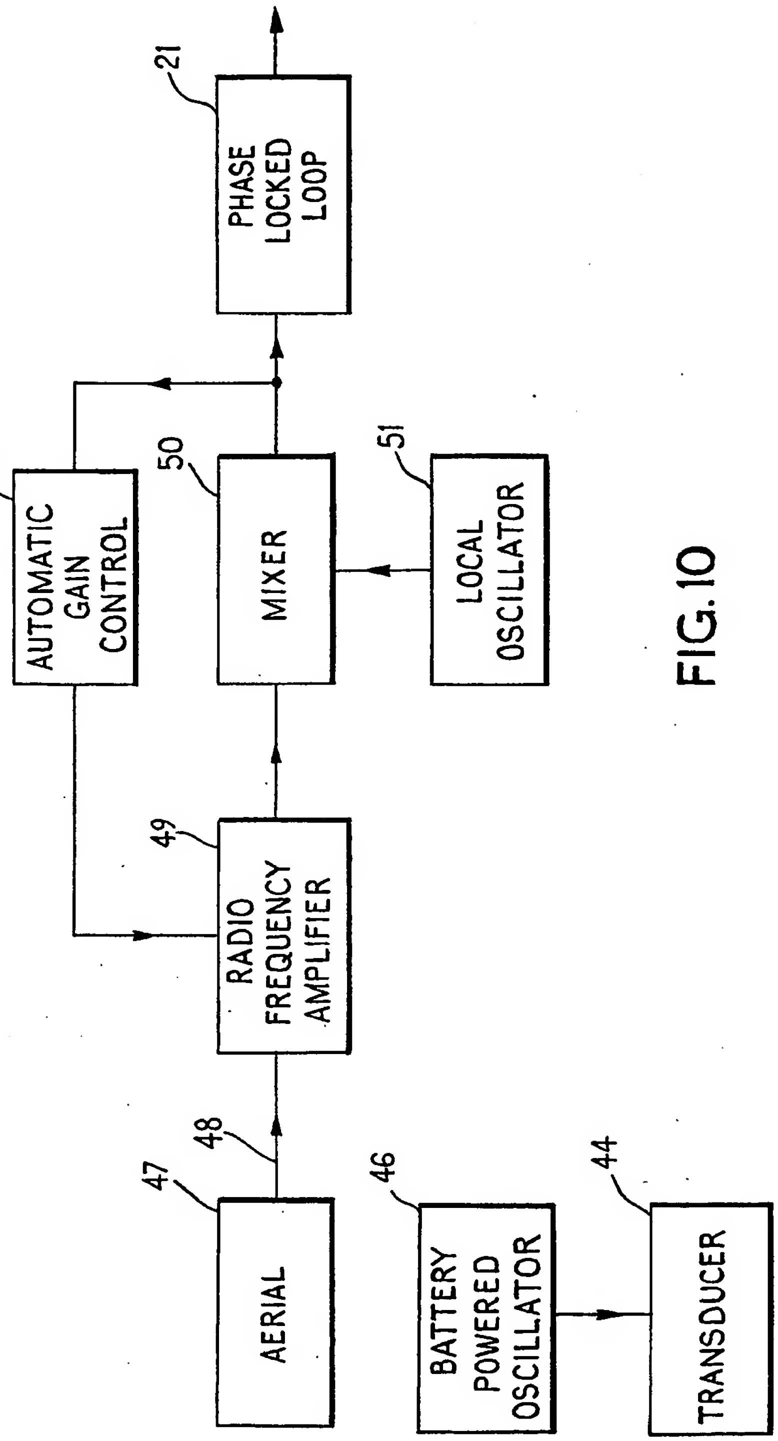


FIG.8

FIG.9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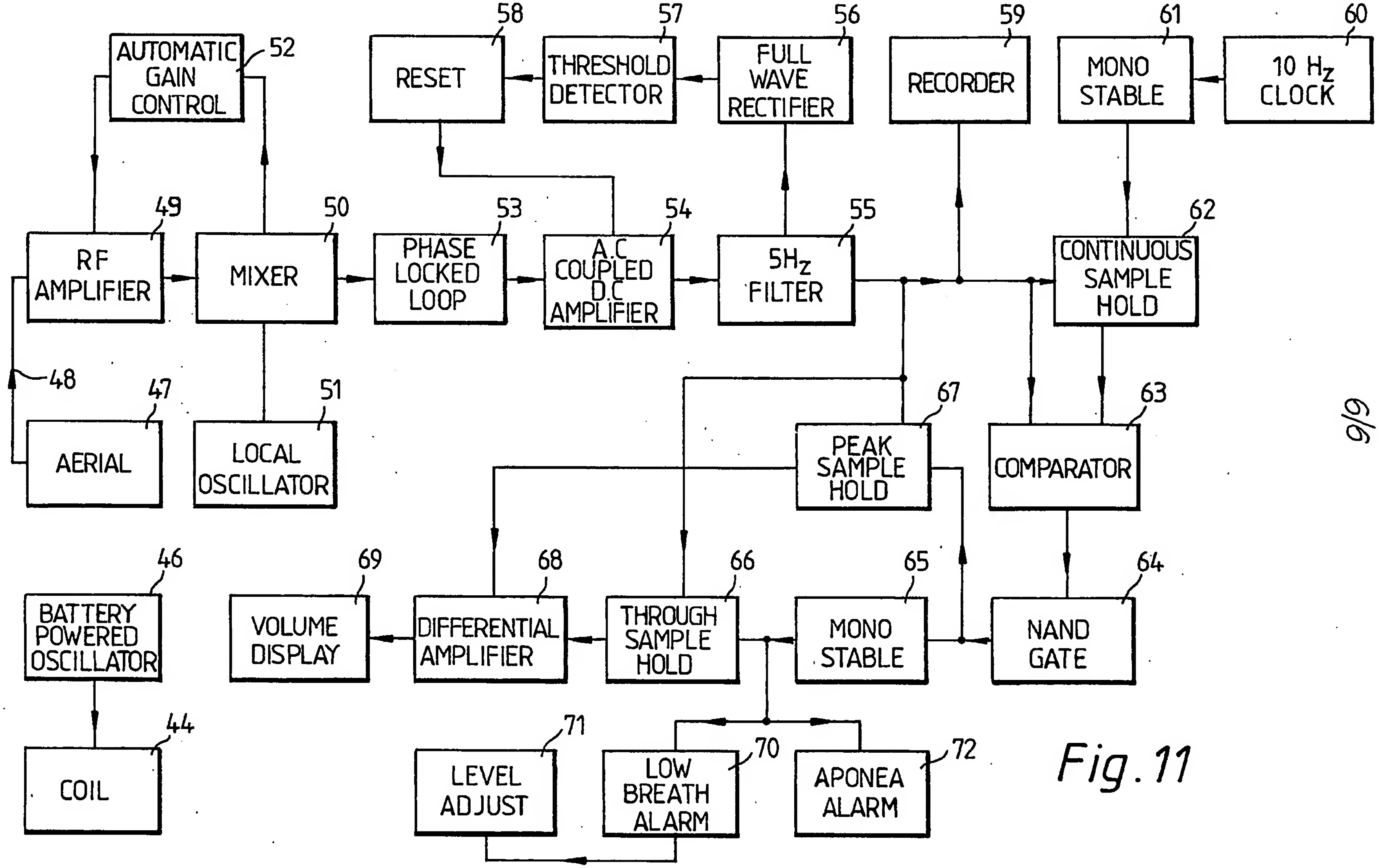
AUTOMATIC GAIN CONTROL
52
MIXER
50
LOCAL OSCILLATOR
51
RADIO FREQUENCY AMPLIFIER
49
AERIAL
47
48
BATTERY POWERED OSCILLATOR
46
TRANSDUCER
44

FIG. 10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RESET
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THRESHOLD DETECTOR
57
FULL WAVE RECTIFIER
56
RECORDER
59
MONO STABLE
61
10 Hz CLOCK
60
RF AMPLIFIER
49
MIXER
50
PHASE LOCKED LOOP
53
A.C COUPLED D.C AMPLIFIER
54
5Hz FILTER
55
CONTINUOUS SAMPLE HOLD
62
48
AERIAL
47
LOCAL OSCILLATOR
51
PEAK SAMPLE HOLD
67
COMPARATOR
63
BATTERY POWERED OSCILLATOR
46
VOLUME DISPLAY
69
DIFFERENTIAL AMPLIFIER
68
THROUGH SAMPLE HOLD
66
MONO STABLE
65
NAND GATE
64
COIL
44
LEVEL ADJUST
71
LOW BREATH ALARM
70
APONEA ALARM
72

Fig. 11

SPECIFICATION

Inductive respiration monitor

The invention relates to apparatus for the detection and monitoring of respiration, in particular to apparatus making use of measurements of changes in inductance occuring in a coil encircling the subject.

The inductance of a coil depends upon its physical dimensions and geometry and by applying a coil in resilient close contact about a body, changes in dimensions of the body, as by breathing, can be followed by changes in the inductance of the coil. Measurements of changes in the inductance of coils encircling the torso of a subject have overcome the difficulties experienced with previous methods of monitoring respiration involving the use of face masks or mouthpieces. The inductive methods are non-invasive, more comfortable and require little co-operation from the subject. These advantages make the inductive methods suitable for monitoring difficult subjects such as babies, critically ill patients and patients undergoing operations.

One known method for monitoring breathing has utilised a coil stitched into an elastic sleeve for encircling the torso. Two such sleeves are in general used: one for the thorax and one for the abdomen so as to reliably monitor breathing. The calibration necessary for this method is fairly complex and is not suitable to be carried out by unskilled staff. The presently known inductive methods also require circuit connections from the inductance coils encircling the subject to the inductance measuring equipment. Where tiny babies are to be monitored it is a disadvantage of existing equipment that wires must be attached to the babies.

The object of the present invention is to provide an inductive apparatus for respiration monitoring which overcomes some of the disadvantages of existing monitors.

A respiration monitor according to the present invention comprises an extensible coil for close encirclement about the body of a subject, the coil being wound in a plurality of turns each turn being wound in the opposite sense to the previous turn, and means for measuring changes in the inductance of the coil arising from the respiration of the subject.

By this means the coil can be incorporated in a garment which can be opened along its entire length without breaking any electrical connections. Thus the garment can be readily applied to a subject without drawing it over the head. Preferably the coil comprises an insulated wire incorporated in an elastic tape, the tape being attached to the garment as a single length in a series of alternating rows extending over the parts of the garment covering the thorax and the abdomen. The garment may take the form of a vest with a releasable front fastening and with channels provided in the body of the vest for retention of the tape to thereby form the turns of the coil. An appropriately sized detachable front panel may be attached to the complementary portions of the front fastening so that the garment can be fitted to subjects of different size.

The garment is preferably made so as to be comfortable to wear without causing perspiration. Cotton is thus a suitable material for the garment with elasticity necessary to maintain the turns of the coil in contact with the body being provided by the elastic tape to which the wire is attached.

Advantageously the monitor has a single coil capable of encircling the thorax and abdomen of a subject and in forms suitable for monitoring human respiration the coil has eight turns for an adult subject and four turns for an infant. The coil preferably forms an inductive element in a variable frequency oscillator which may be attached to the garment. The oscillator may be battery powered and detached from the remainder of the respiration monitor circuit with the coil acting as a radiative element to transmit energy from the oscillator. This form of monitor is particularly useful for monitoring bodies breathing when it is desirable that there should be no wires attached to the subject. In the form of monitor there is provided a receiving aerial for detecting the radiated energy from the coil. The aerial is placed underneath the subject, for example under a mattress, and the detected signal after amplification is mixed with the output signal from a local oscillator whereby changes in the beat signal output from the mixer are used to represent volumetric changes in the subject due to respiration.

The varying frequency signal, changing in response to respiration, may be converted to an analogue voltage by a phase locked loop circuit. The analogue voltage may then be connected to a DC amplifier preferably such that the amplification is reduced when the DC level of the input signal to the amplifier exceeds a pre-selected threshold. The output signal from the amplifier may be displayed and it may be processed to derive respiratory parameters. Preferably the amplified signal is simultaneously passed through a pre-selected variable phase delay and through an adjustable DC offset circuit and the delay is arranged such that the rising voltage of one output passes through the trough of the other output signal. The outputs from the delay and the DC offset circuits thus arranged are connected from a comparator to a monostable the integrated output of which gives an indication of the respiration rate. The comparator activates a sample and hold circuit which detects the trough and on subtracting this value from the amplified output signal the remainder represents the volume of air within the body of the subject.

The monitor may incorporate an alarm signal adapted to operate when any desired parameter of the respiration (eg breathing rate) reaches a pre-selected level.

The invention will now be described by way of example only with reference to the accompanying drawings of which:

Figure 1 is a diagrammatic representation of an inductive coil according to the present invention;

Figure 2 shows an inductive coil wire knitted into an elasticated tape;

Figure 3 shows an open vest incorporating the inductive coil;

Figure 4 shows the Figure 3 vest as it is worn;

Figure 5 indicates apparatus for incorporating the

coil in the vest;

Figure 6 is a block diagram of the circuit arrangement of the respiration monitor;

Figure 7 shows the output signals from the phase delay and the DC offset circuits in Figure 6;

Figures 8 and *9* show an alternative form of garment suitable for an infant;

Figure 10 is a block diagram of a modification to the Figure 6 circuit arrangement for monitoring infants; and

Figure 11 is a block diagram of an alternative modification also suitable for monitoring infants.

As shown in Figure 1 a single coil 1 of eight turns of wire is provided to be arranged around the thorax and abdomen of a patient for respiration monitoring. The wire 2 is conventional PVC coated multicore wire with adjacent turns 3, 4 etc passing in the opposite sense with respect to each other. Each successive turn is arranged to turn back on itself adjacent to a mid line 5 parallel to the axis 6 of the coil 1. The coil 1 thus forms a cylinder which can be opened about the mid lines 5 without the need for breaking electrical connections. The ends 7 and 8 of the coil 1 are connected to an oscillator 9 having a cable with twin core terminal wires 10 and 11.

The wire 2 is supported on an elasticated tape 12 as shown in Figure 2 and is introduced into the tape during knitting. The tape 12 consists of two ends of 1/26s cotton and two ends of uncovered latex yarn knitted together in an open 1 × 1 rib basis. Prior to every fourth knitting course an inlay of 7 × 0.1 mm stranded PVC covered wire is introduced to give the pattern shown. The tape may also be constructed as a warp-knitted crochet structure, the width of tape being determined by the number of vertical chains or wales. An elasticity is produced by laying an elastic yarn into the cotton chaining. The wire 2 may be incorporated into the structure in any desired pattern by laying it into the cotton chaining.

The tape 12 is mounted in channels 13 formed within a rib-knitted garment 14 of an appropriate size as shown in Figures 3 and 4. The garment 14 is produced on an 8-gauge rib machine from four ends of 1/26s carded and combed cotton. The garment body consists of a very open 1 × 1 rib with plain knit selvedge strips integral with the body width. Lateral pockets of a plain knit basis are knitted in the body in a tubular construction of a suitable size to form the eight channels 13 for accompanying the tape 12. The shape of the garment 14 when opened out is shown in Figure 3 and is shown as worn in Figure 4. The garment 14 is fastened at the front by a full-length zip fastener 15 and the shoulder straps 16 are fastened with Velcro or pop fasteners or any other suitable means such as hook and eye or lacing. Similarly any suitable fastening may be used in place of the Velcro shoulder strap fasteners.

To accommodate extra large subjects a separate extension panel may be fitted to the front of the garment. This panel consists of a full length strip of rib knitted cotton of appropriate width with a full length zip fastener portion at each long edge. The panel is zipped into the front of the garment by means of the two zip fasteners.

One method for inserting the tape 12 into the channels 13 is shown in Figure 5. A tube 18 closed at one end by a removable conically shaped end cap 19 is pushed into a channel 13. When the tube 18 is in position a wire loop 20 is used to pull the tape 12 through the tube 18 before removing the tube. This procedure is then repeated for all the channels. Alternatively a tube with a "C" cross-section may be used to enable the tape to be removed more easily from the tube.

The principle of operation of the inductive coil is that the coil forms the inductive element of a variable frequency oscillator. As the volume of the coil alters due to respiration the inductance varies and hence the frequency of oscillation. The change in frequency of the oscillator 9 is used as indicated in the block circuit diagram of Figure 6 by converting the frequency change to an analogue voltage by a phase locked loop circuit 21. The analogue signal is passed to an AC coupled DC amplifier 22 with a time constant of about 22 secs. The signal is also passed to a full wave rectifier 23 and then to a threshold detector 24. When the rectified voltage exceeds a pre-selected threshold limit the threshold detector 24 activates a reset circuit 25 which shortens the time constant of the AC coupled amplifier 22 to approximately 300 msec. The reset circuit 25 thus serves to restore the signal rapidly towards the base-line when it exceeds a pre-selected limit. The amplified signal can then be fed to any suitable recorder 26 or display device for example an oscilloscope, pen or tape recorder or computer. A microprocessor may be used to facilitate calibration, derive respiratory parameters such as tidal volume, minute volume and inspiratory and expiratory times and to provide a warning of a cessation or reduction of breathing.

The signal from the amplifier 22 also passes to a phase delay 27 which applies a selectable phase delay. In addition the amplified signal passes to a DC offset circuit 28 which provides a DC offset of about −50 millivolts. The degree of phase delay 29 (see Figure 7) is arranged so that the trough 30 of the output from the delay 27 (solid line) is intersected by the rising voltage 31 of the offset signal from the DC offset 28 (dashed line). The DC offset is shown as the vertical separation 32 of the troughs 30 and 33 of the two signals. The intersection is detected by a comparator 34 which activates a circuit 35 which samples and holds the voltage of the trough 30 of the phase delayed signal. This voltage is fed to one input 36 of a differential amplifier 37. The phase delayed signal is fed to the other input 38 of the differential amplifier and the resultant output, which represents the temporal change of the volume of air within the subject, is passed to a suitable display 39 such as a column of light emitting diodes giving an indication of the tidal volume (volume of each breath). A gain control is provided to adjust the output of the differential amplifier 37 for calibration purposes. An alarm circuit 40 is activated if ten successive breaths do not exceed an adjustable pre-selected volume. The output from the comparator 34, which represents the commencement of each breath, is also passed to a rate meter circuit 41 which displays an indication of the respiratory rate on a

panel meter or other suitable display. An alarm circuit 42 is also activated if no breath is detected in an ajustable pre-selected time interval.

Calibration of the respiration monitor is achieved by simultaneously permitting the subject to breathe into any suitable spirometer or respirometer which will provide an indication of tidal volume, or into a bag of known volume, and adjusting the gain control to obtain an appropriate indication of tidal volume. This method has been found to be sufficiently accurate for clinical purposes and overcomes shortcomings in the prior art arrangements since it is fairly simple to perform.

An alternative form of garment 43 suitable for infants is shown in Figures 8 and 9. The construction of this garment is similar to that described above except that only four turns of wire are used for the coil 44. The garment 43 has additional Velcro fasteners 45 so that it may be joined under the crutch. The circuitry of the respiration monitor in this case is identical to that shown in Figure 6 from the phase locked loop 21 onwards. The rest of the circuitry up to and including the phase locked loop 21 is shown in Figure 10. The coil 44 or transducer and oscillator 46 are a separate unit powered by rechargeable batteries and attached to the garment 43. Since there is an oscillating signal in the coil 44 energy is radiated from the coil 44 at between 1.5 and 1.6 MHz, the frequency of the oscillator. This radiated signal is detected by an aerial 47 placed under a cot mattress on which the infant lies. The aerial 47 is composed of five rectangular loops of insulated copper wire measuring approximately 18 × 25 cm sandwiched between two sheets of flexible plastics material Any other configuration of aerial may also be suitable. The aerial 47 is connected to the remaining monitor circuitry by screened cable 48. The detected signal passes through an rf amplifier 49. The amplified signal is then applied to a mixer 50 where it is mixed with the output of a local oscillator 51, producing a beat frequency which is passed to the phase locked loop 21. An automatic gain control circuit 52 modulates the gain of the rf amplifier 49 to maintain a constant amplitude independent of the orientation of the coil 44 relative to the aerial 47.

A further circuit for a monitor suitable for use with infants is illustrated schematically in Figure 11, the part of the circuit up to and including the phase locked loop 53 being identical to that described with reference to Figure 10. In this embodiment, the phase locked loop circuit 53 converts the beat frequency into an analogue voltage which is passed to an AC coupled DC amplifier 54 with a time constant of about 10 msecs. The analogue signal then passes to a 5Hz low pass filter 55. The filtered signal is passed to a full wave rectifier 56 and then to a threshold detector 57. When the rectified voltage exceeds a pre-selected threshold limit the threshold detector 57 activates a reset circuit 58 which shortens the time constant of the AC coupled DC amplifier 54 to about 180 msec. The reset circuit 58 thus serves to restore the signal rapidly towards the baseline when it exceeds a pre-selected limit. The filtered signal can then be fed to a recorder 59 or display device as before.

The output from a 10Hz clock 60 is used to trigger a monostable 61 whose output is used to trigger a continuous sample hold 62. The signal from the 5Hz filter 55 is fed into the continuous sample hold 62 and also into one input of a comparator 63. The output 74 from the continuous sample hold 62, which lags behind the filtered signal, is fed into the other input of the comparator 63. When the filtered signal is falling from a peak to a trough it is more negative than the output 74 and the output of the comparator 63 is high. When the filtered signal passes the trough and starts rising towards the peak it becomes more positive than the output 74 and the output of the comparator 63 goes low. The output of the comparator 63 passes through a NAND gate 64, which inverts it, and this inverted signal is used to trigger a peak sample hold 67. When the output of the comparator 63 passes through a NAND gate 64 goes high (at each trough) the peak sample hold 67 starts to sample and continues to do so until the output of the NAND gate 64 foes low (at each peak) at which point it holds that voltage (the peak voltage) until the next trough occurs and the NAND gate 64 output goes high again. The signal from the NAND gate 64 also passes to a monostable 65 which gives an output pulse each time a trough occurs. This pulse then triggers a trough sample hold 66 which then holds the trough voltage. The outputs of the peak sample hold 64 and the trough sample hold 66 are passed respectively to the two inputs of a differential amplifier 68 and the resultant output, which represents the temporal change of the volume of air within the infant, is passed to a suitable display 69 such as a column of light emitting diodes giving an indication of the volume of each breath (tidal volume). A gain control is provided to adjust the output of the differential amplifier 68 for calibration purposes.

The output of monostable 65, which represents the commencement of each breath passes to two alarm circuits. An apnoea alarm 72 is activated if no breath is detected in an adjustable pre-selected time interval. A low breath alarm 70 is activated if seven successive breaths do not exceed a volume pre-selected by the level adjust 71.

These forms of monitoring offer the advantage that there are no wires to restrict or interfere with the movements of the subject. In addition where infants are being monitored to help prevent "cot-death", parents might be inhibited from handling their infants because of the presence of attached wires or tubing. The invention overcomes this reluctance which, if present, could adversely affect the psychological bond between a mother and her infant.

The respiration monitor may be modified by monitoring, in addition to the volumetric changes in the inductance coil, the relative phase of an upper turn of the coil around the thorax and a lower turn of the coil around the abdomen. During paradoxical breathing when the exterior wind tracts are blocked abdominal and thoracic movements become in anti-phase and thus when anti-phase movements are detected this may also be used to trigger an alarm.

Detailed circuit diagrams have not been given as the block diagrams described include known circuit arrangements. Variations in the respiration monitor from the arrangements described will be apparent to those skilled in the art while falling within the scope of the invention defined herein.

CLAIMS

1. A respiration monitor comprising an extensible coil for close encirclement about the body of a subject, the coil being wound in a plurality of turns with each turn being wound in the opposite sense to the preceding turn, and means for measuring changes in the inductance of the coil arising from the respiration of the subject.

2. A respiration monitor according to Claim 1 in which the coil is incorporated in a garment which can be opened along its entire length without breaking any electrical connection.

3. A respiration monitor according to Claim 2 in which the coil consists of a length of insulated wire incorporated in an elastic tape, the tape being attached to the garment as a single length in a series of alternating rows extending over the parts of the garment covering the thorax and abdomen.

4. A respiration monitor according to any preceding claim in which the coil forms an inductive element in a variable frequency oscillator.

5. A respiration monitor according to Claim 4 in which the oscillator is battery powered and attached to the garment, the coil acting as a radiative element to transmit energy from the oscillator, the respiration monitor incorporating a receiving aerial for detecting the energy transmitted from the coil.

6. A respiration monitor according to any preceding claim incorporating an alarm signal adapted to operate when any desired parameter of the respiration reaches a pre-selected level.

7. A respiration monitor incorporating a garment substantially as described with reference to Figures 3 and 4 or 8 and 9.

8. A respiration monitor, substantially as described with reference to Figures 6, 10 or 11.

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(51) INT CL³ A61B 5/08
(52) Domestic classification G1N 19B2F 19D10 19D12F0 19X5 19X6 30P5 3QR ENR
(56) Documents cited GB 1596298
(58) Field of search G1N

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Room 2014 20th Floor,
Empress State Buildings,
Lillie Road,
London SW6 1TR.

(54) Respiration monitor

(57) Apparatus for monitoring the respiration of subjects, particularly hospital patients or infants, includes an inductive coil of insulated wire mounted on elasticated tape 12, the tape being sewn or threaded in channels 13 on a garment 14 as a single length in alternating rows, arranged so that in use the coil comprises a plurality of turns encircling the body, each turn being wound in the opposite sense to the preceding turn, and the garment may be opened completely without breaking any electrical connections. The coil may form an inductive element in a variable frequency oscillator, frequency changes in which can be processed electronically to provide continuous information of the respiratory parameters. In an embodiment particularly suitable for use with infants, the coil may form a radiative element in a

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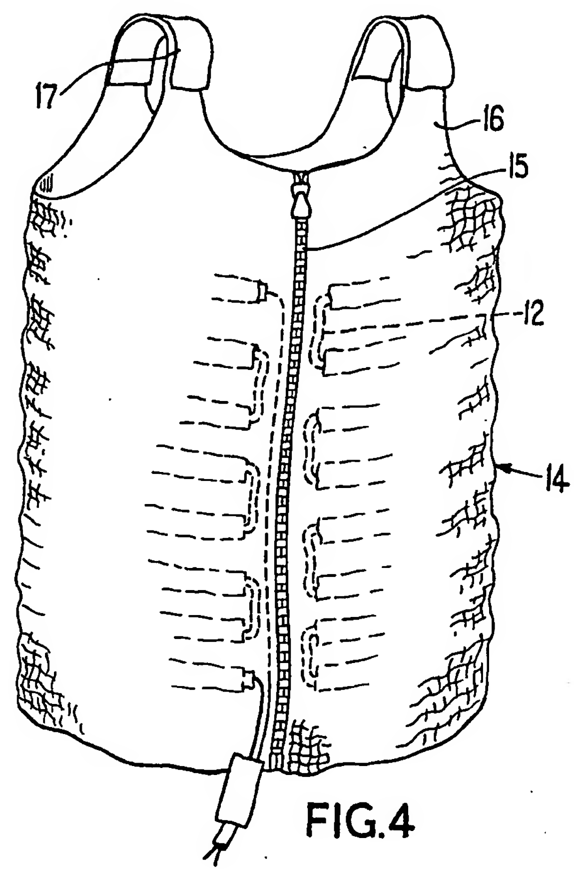

FIG.4

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battery-powered oscillator isolated from the remainder of the monitor circuit. The radiation is detected and transmitted to the circuit by an aerial which may be conveniently placed under a cot mattres.

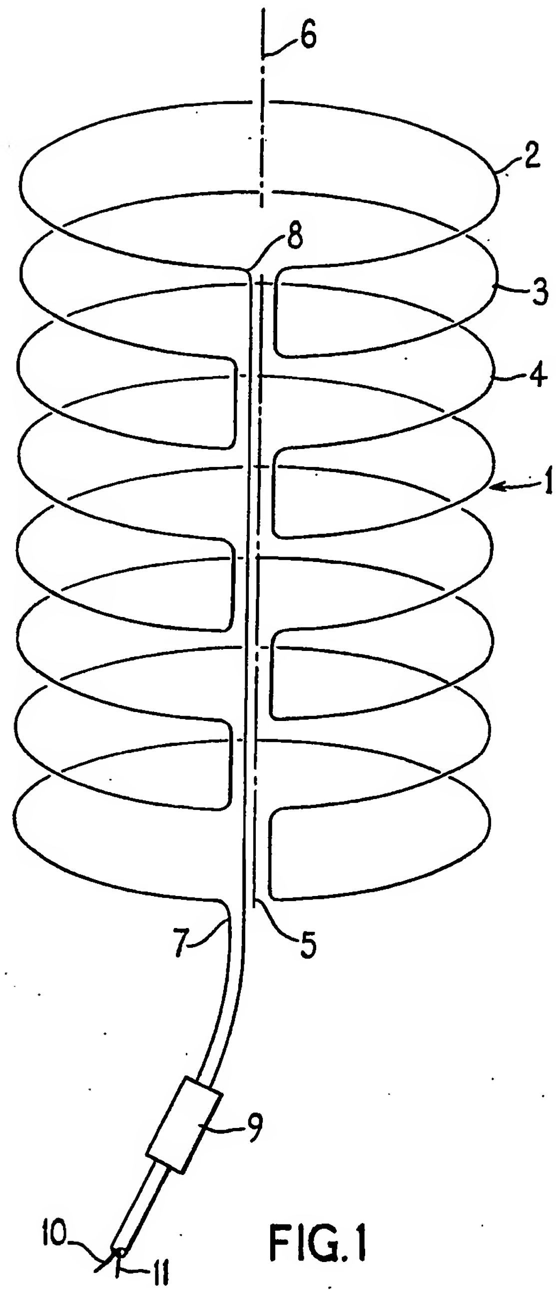


FIG.1

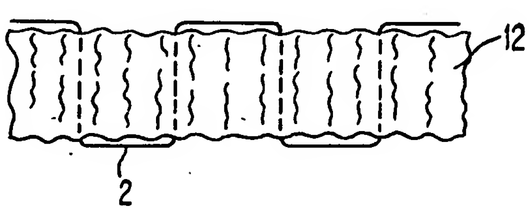


FIG.2

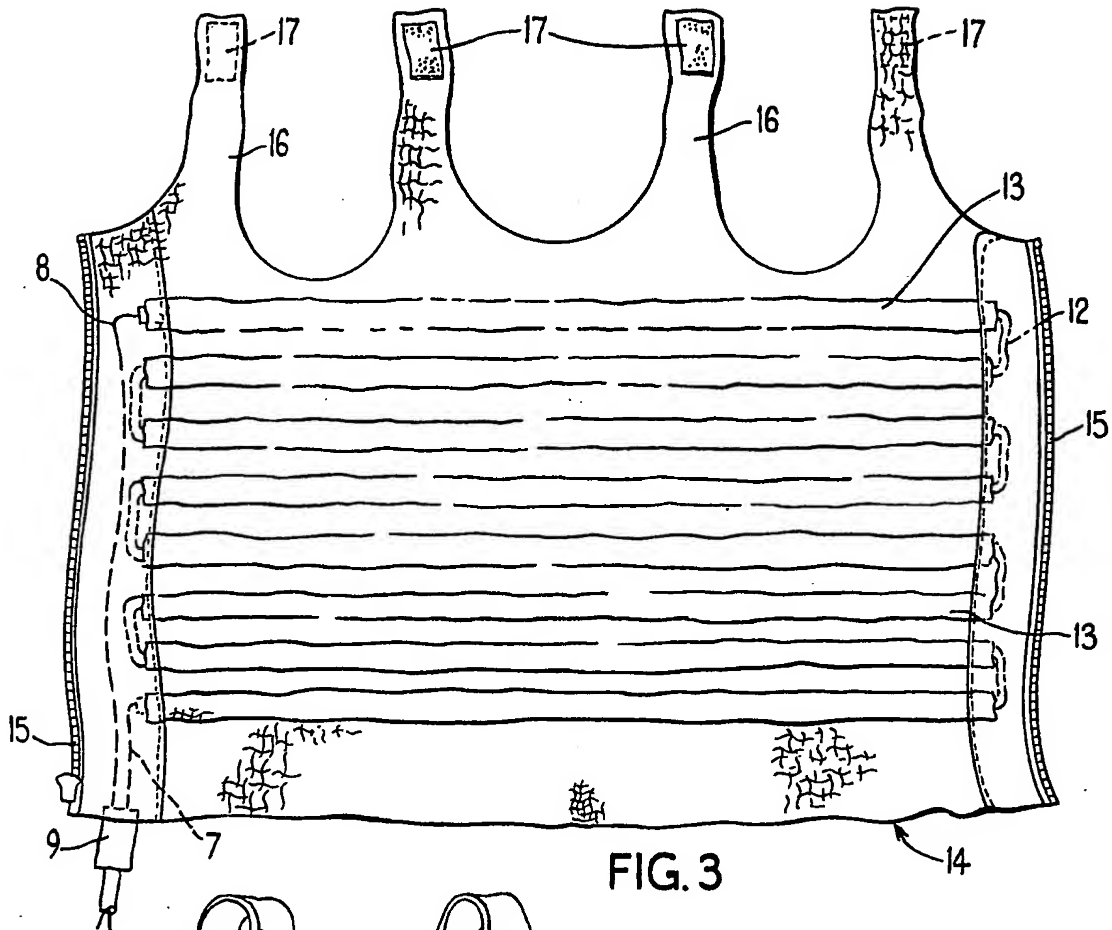


FIG. 3

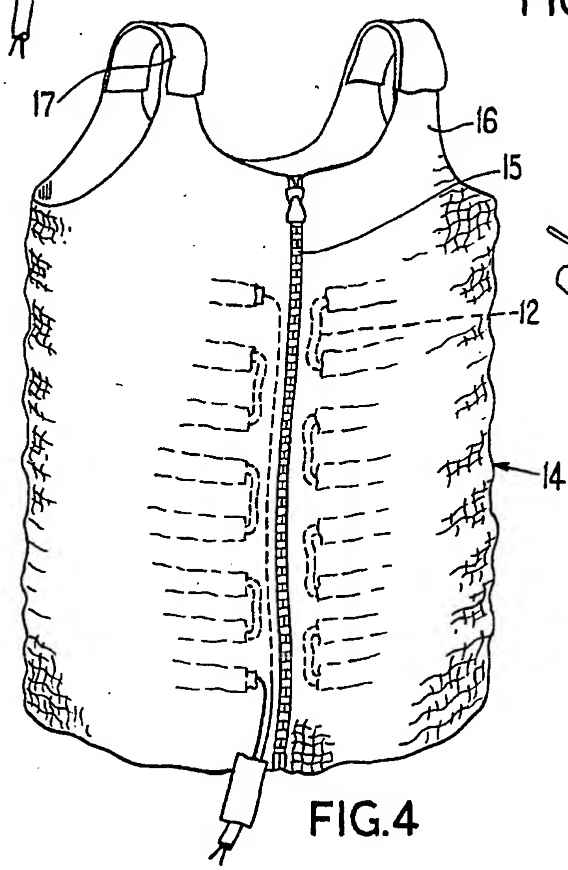


FIG.4

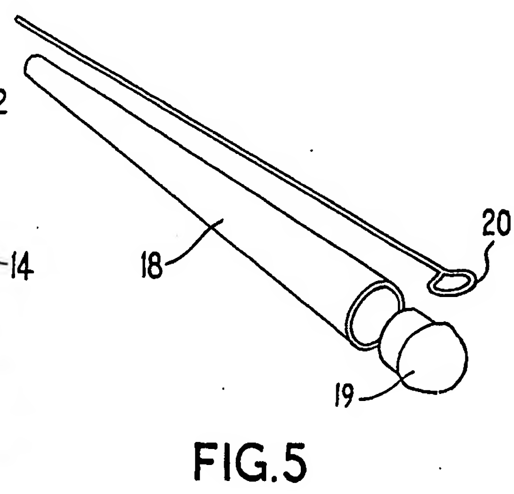
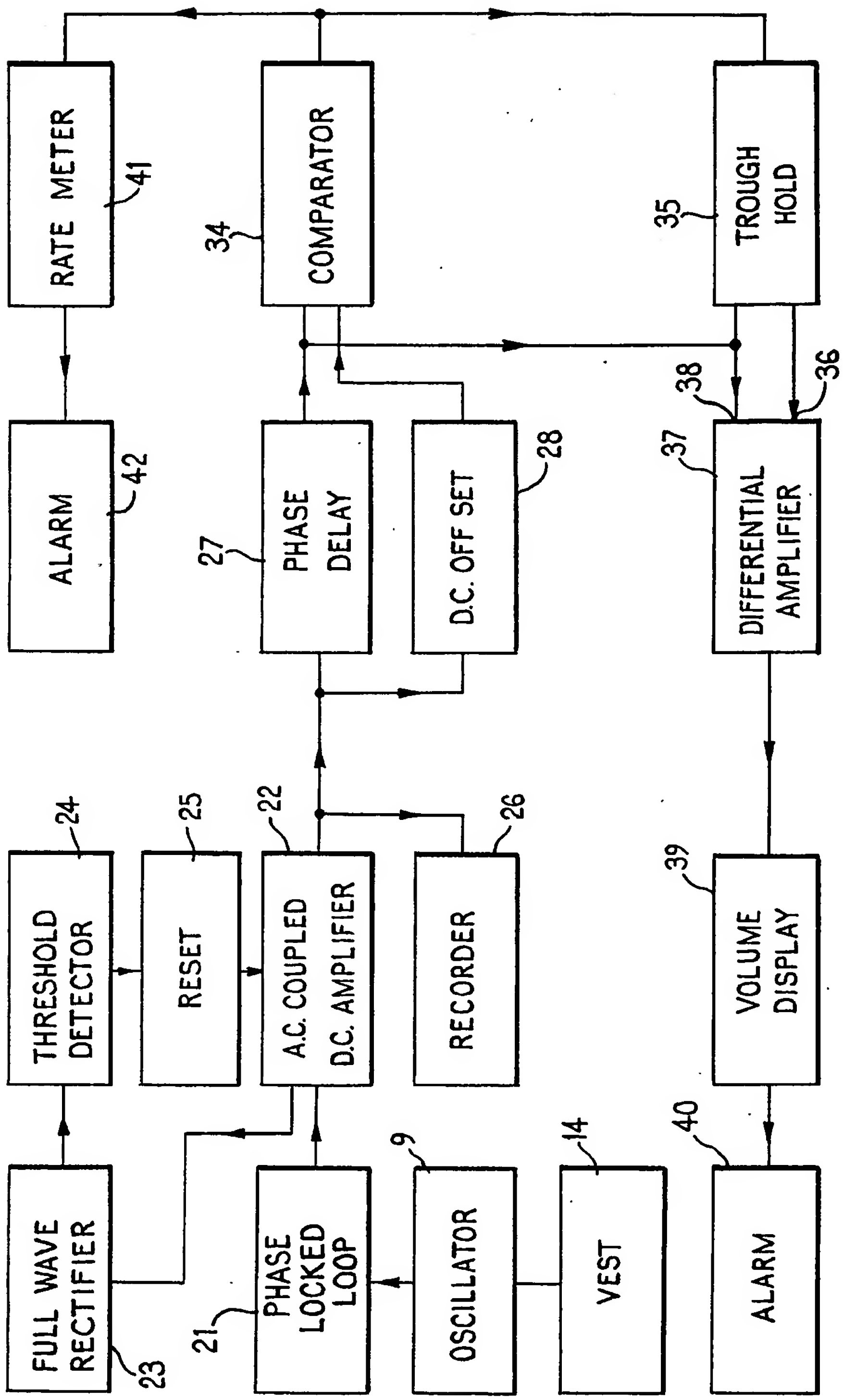


FIG.5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ALARM
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PHASE DELAY
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THRESHOLD DETECTOR
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RESET
25
A.C. COUPLED D.C. AMPLIFIER
22
RECORDER
26
VOLUME DISPLAY
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FULL WAVE RECTIFIER
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ALARM
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FIG.6

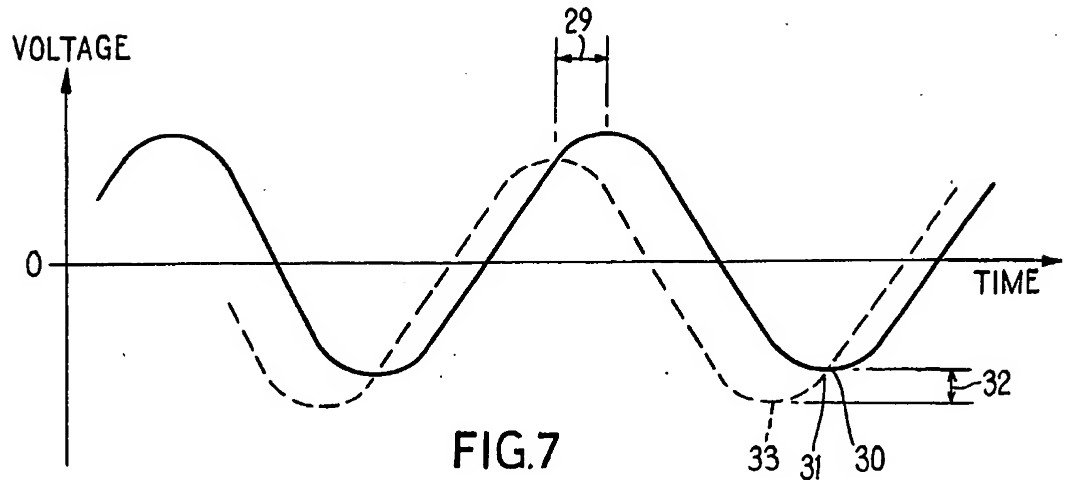
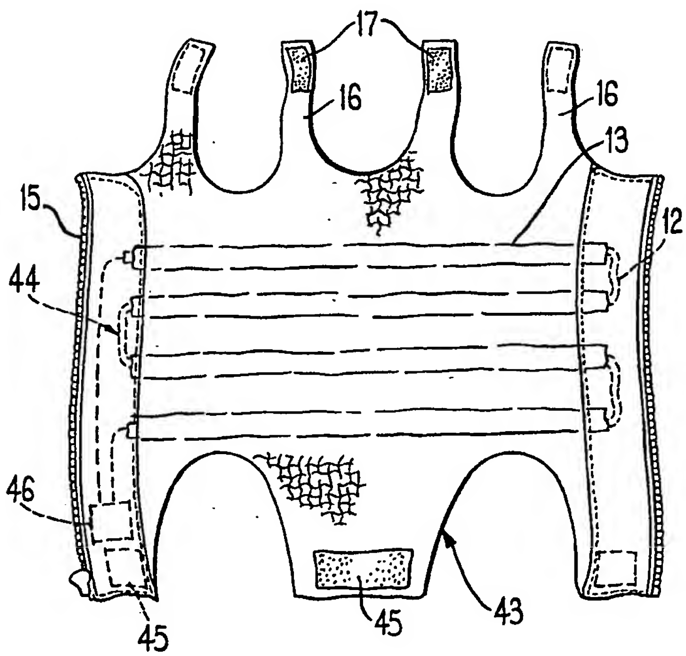


FIG.7



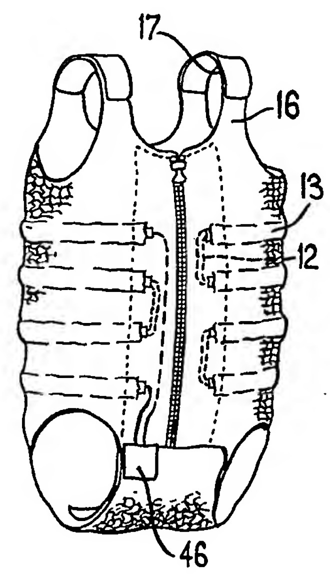


FIG.8

FIG.9

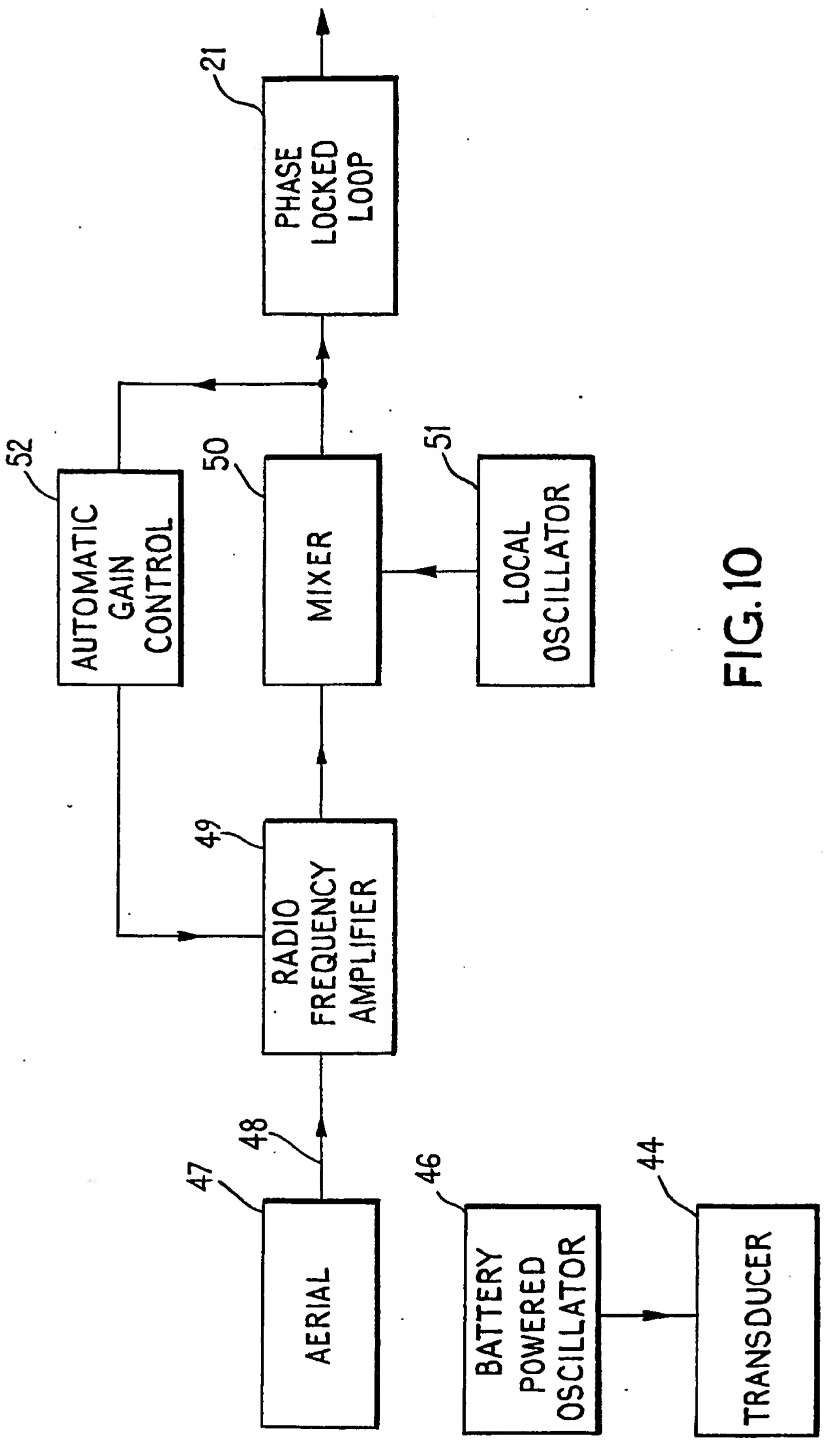

21
PHASE LOCKED LOOP
52
AUTOMATIC GAIN CONTROL
50
MIXER
51
LOCAL OSCILLATOR
49
RADIO FREQUENCY AMPLIFIER
47
48
AERIAL
46
BATTERY POWERED OSCILLATOR
44
TRANSDUCER

FIG. 10

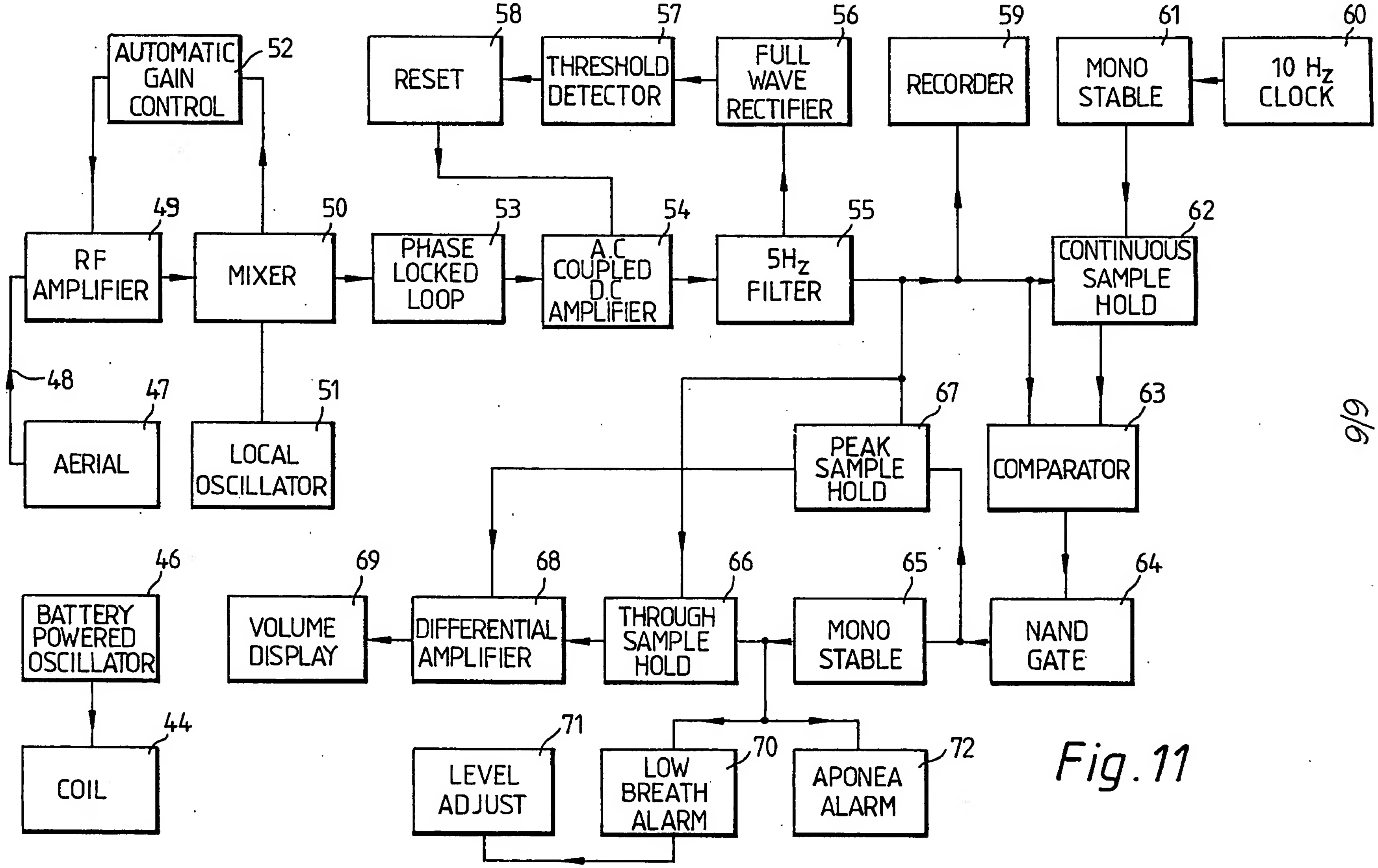

AUTOMATIC GAIN CONTROL
52
RESET
58
THRESHOLD DETECTOR
57
FULL WAVE RECTIFIER
56
RECORDER
59
MONO STABLE
61
10 Hz CLOCK
60
RF AMPLIFIER
49
MIXER
50
PHASE LOCKED LOOP
53
A.C COUPLED D.C AMPLIFIER
54
5Hz FILTER
55
CONTINUOUS SAMPLE HOLD
62
48
AERIAL
47
LOCAL OSCILLATOR
51
PEAK SAMPLE HOLD
67
COMPARATOR
63
BATTERY POWERED OSCILLATOR
46
VOLUME DISPLAY
69
DIFFERENTIAL AMPLIFIER
68
THROUGH SAMPLE HOLD
66
MONO STABLE
65
NAND GATE
64
COIL
44
LEVEL ADJUST
71
LOW BREATH ALARM
70
APONEA ALARM
72

Fig. 11

SPECIFICATION

Inductive respiration monitor

The invention relates to apparatus for the detection and monitoring of respiration, in particular to apparatus making use of measurements of changes in inductance occuring in a coil encircling the subject.

The inductance of a coil depends upon its physical dimensions and geometry and by applying a coil in resilient close contact about a body, changes in dimensions of the body, as by breathing, can be followed by changes in the inductance of the coil. Measurements of changes in the inductance of coils encircling the torso of a subject have overcome the difficulties experienced with previous methods of monitoring respiration involving the use of face masks or mouthpieces. The inductive methods are non-invasive, more comfortable and require little co-operation from the subject. These advantages make the inductive methods suitable for monitoring difficult subjects such as babies, critically ill patients and patients undergoing operations.

One known method for monitoring breathing has utilised a coil stitched into an elastic sleeve for encircling the torso. Two such sleeves are in general used: one for the thorax and one for the abdomen so as to reliably monitor breathing. The calibration necessary for this method is fairly complex and is not suitable to be carried out by unskilled staff. The presently known inductive methods also require circuit connections from the inductance coils encircling the subject to the inductance measuring equipment. Where tiny babies are to be monitored it is a disadvantage of existing equipment that wires must be attached to the babies.

The object of the present invention is to provide an inductive apparatus for respiration monitoring which overcomes some of the disadvantages of existing monitors.

A respiration monitor according to the present invention comprises an extensible coil for close encirclement about the body of a subject, the coil being wound in a plurality of turns each turn being wound in the opposite sense to the previous turn, and means for measuring changes in the inductance of the coil arising from the respiration of the subject.

By this means the coil can be incorporated in a garment which can be opened along its entire length without breaking any electrical connections. Thus the garment can be readily applied to a subject without drawing it over the head. Preferably the coil comprises an insulated wire incorporated in an elastic tape, the tape being attached to the garment as a single length in a series of alternating rows extending over the parts of the garment covering the thorax and the abdomen. The garment may take the form of a vest with a releasable front fastening and with channels provided in the body of the vest for retention of the tape to thereby form the turns of the coil. An appropriately sized detachable front panel may be attached to the complementary portions of the front fastening so that the garment can be fitted to subjects of different size.

The garment is preferably made so as to be comfortable to wear without causing perspiration. Cotton is thus a suitable material for the garment with elasticity necessary to maintain the turns of the coil in contact with the body being provided by the elastic tape to which the wire is attached.

Advantageously the monitor has a single coil capable of encircling the thorax and abdomen of a subject and in forms suitable for monitoring human respiration the coil has eight turns for an adult subject and four turns for an infant. The coil preferably forms an inductive element in a variable frequency oscillator which may be attached to the garment. The oscillator may be battery powered and detached from the remainder of the respiration monitor circuit with the coil acting as a radiative element to transmit energy from the oscillator. This form of monitor is particularly useful for monitoring bodies breathing when it is desirable that there should be no wires attached to the subject. In the form of monitor there is provided a receiving aerial for detecting the radiated energy from the coil. The aerial is placed underneath the subject, for example under a mattress, and the detected signal after amplification is mixed with the output signal from a local oscillator whereby changes in the beat signal output from the mixer are used to represent volumetric changes in the subject due to respiration.

The varying frequency signal, changing in response to respiration, may be converted to an analogue voltage by a phase locked loop circuit. The analogue voltage may then be connected to a DC amplifier preferably such that the amplification is reduced when the DC level of the input signal to the amplifier exceeds a pre-selected threshold. The output signal from the amplifier may be displayed and it may be processed to derive respiratory parameters. Preferably the amplified signal is simultaneously passed through a pre-selected variable phase delay and through an adjustable DC offset circuit and the delay is arranged such that the rising voltage of one output passes through the trough of the other output signal. The outputs from the delay and the DC offset circuits thus arranged are connected from a comparator to a monostable the integrated output of which gives an indication of the respiration rate. The comparator activates a sample and hold circuit which detects the trough and on subtracting this value from the amplified output signal the remainder represents the volume of air within the body of the subject.

The monitor may incorporate an alarm signal adapted to operate when any desired parameter of the respiration (eg breathing rate) reaches a pre-selected level.

The invention will now be described by way of example only with reference to the accompanying drawings of which:

Figure 1 is a diagrammatic representation of an inductive coil according to the present invention;

Figure 2 shows an inductive coil wire knitted into an elasticated tape;

Figure 3 shows an open vest incorporating the inductive coil;

Figure 4 shows the Figure 3 vest as it is worn;

Figure 5 indicates apparatus for incorporating the

coil in the vest;

Figure 6 is a block diagram of the circuit arrangement of the respiration monitor;

Figure 7 shows the output signals from the phase delay and the DC offset circuits in Figure 6;

Figures 8 and *9* show an alternative form of garment suitable for an infant;

Figure 10 is a block diagram of a modification to the Figure 6 circuit arrangement for monitoring infants; and

Figure 11 is a block diagram of an alternative modification also suitable for monitoring infants.

As shown in Figure 1 a single coil 1 of eight turns of wire is provided to be arranged around the thorax and abdomen of a patient for respiration monitoring. The wire 2 is conventional PVC coated multicore wire with adjacent turns 3, 4 etc passing in the opposite sense with respect to each other. Each successive turn is arranged to turn back on itself adjacent to a mid line 5 parallel to the axis 6 of the coil 1. The coil 1 thus forms a cylinder which can be opened about the mid lines 5 without the need for breaking electrical connections. The ends 7 and 8 of the coil 1 are connected to an oscillator 9 having a cable with twin core terminal wires 10 and 11.

The wire 2 is supported on an elasticated tape 12 as shown in Figure 2 and is introduced into the tape during knitting. The tape 12 consists of two ends of 1/26s cotton and two ends of uncovered latex yarn knitted together in an open 1 × 1 rib basis. Prior to every fourth knitting course an inlay of 7 × 0.1 mm stranded PVC covered wire is introduced to give the pattern shown. The tape may also be constructed as a warp-knitted crochet structure, the width of tape being determined by the number of vertical chains or wales. An elasticity is produced by laying an elastic yarn into the cotton chaining. The wire 2 may be incorporated into the structure in any desired pattern by laying it into the cotton chaining.

The tape 12 is mounted in channels 13 formed within a rib-knitted garment 14 of an appropriate size as shown in Figures 3 and 4. The garment 14 is produced on an 8-gauge rib machine from four ends of 1/26s carded and combed cotton. The garment body consists of a very open 1 × 1 rib with plain knit selvedge strips integral with the body width. Lateral pockets of a plain knit basis are knitted in the body in a tubular construction of a suitable size to form the eight channels 13 for accompanying the tape 12. The shape of the garment 14 when opened out is shown in Figure 3 and is shown as worn in Figure 4. The garment 14 is fastened at the front by a full-length zip fastener 15 and the shoulder straps 16 are fastened with Velcro or pop fasteners or any other suitable means such as hook and eye or lacing. Similarly any suitable fastening may be used in place of the Velcro shoulder strap fasteners.

To accommodate extra large subjects a separate extension panel may be fitted to the front of the garment. This panel consists of a full length strip of rib knitted cotton of appropriate width with a full length zip fastener portion at each long edge. The panel is zipped into the front of the garment by means of the two zip fasteners.

One method for inserting the tape 12 into the channels 13 is shown in Figure 5. A tube 18 closed at one end by a removable conically shaped end cap 19 is pushed into a channel 13. When the tube 18 is in position a wire loop 20 is used to pull the tape 12 through the tube 18 before removing the tube. This procedure is then repeated for all the channels. Alternatively a tube with a "C" cross-section may be used to enable the tape to be removed more easily from the tube.

The principle of operation of the inductive coil is that the coil forms the inductive element of a variable frequency oscillator. As the volume of the coil alters due to respiration the inductance varies and hence the frequency of oscillation. The change in frequency of the oscillator 9 is used as indicated in the block circuit diagram of Figure 6 by converting the frequency change to an analogue voltage by a phase locked loop circuit 21. The analogue signal is passed to an AC coupled DC amplifier 22 with a time constant of about 22 secs. The signal is also passed to a full wave rectifier 23 and then to a threshold detector 24. When the rectified voltage exceeds a pre-selected threshold limit the threshold detector 24 activates a reset circuit 25 which shortens the time constant of the AC coupled amplifier 22 to approximately 300 msec. The reset circuit 25 thus serves to restore the signal rapidly towards the base-line when it exceeds a pre-selected limit. The amplified signal can then be fed to any suitable recorder 26 or display device for example an oscilloscope, pen or tape recorder or computer. A microprocessor may be used to facilitate calibration, derive respiratory parameters such as tidal volume, minute volume and inspiratory and expiratory times and to provide a warning of a cessation or reduction of breathing.

The signal from the amplifier 22 also passes to a phase delay 27 which applies a selectable phase delay. In addition the amplified signal passes to a DC offset circuit 28 which provides a DC offset of about −50 millivolts. The degree of phase delay 29 (see Figure 7) is arranged so that the trough 30 of the output from the delay 27 (solid line) is intersected by the rising voltage 31 of the offset signal from the DC offset 28 (dashed line). The DC offset is shown as the vertical separation 32 of the troughs 30 and 33 of the two signals. The intersection is detected by a comparator 34 which activates a circuit 35 which samples and holds the voltage of the trough 30 of the phase delayed signal. This voltage is fed to one input 36 of a differential amplifier 37. The phase delayed signal is fed to the other input 38 of the differential amplifier and the resultant output, which represents the temporal change of the volume of air within the subject, is passed to a suitable display 39 such as a column of light emitting diodes giving an indication of the tidal volume (volume of each breath). A gain control is provided to adjust the output of the differential amplifier 37 for calibration purposes. An alarm circuit 40 is activated if ten successive breaths do not exceed an adjustable pre-selected volume. The output from the comparator 34, which represents the commencement of each breath, is also passed to a rate meter circuit 41 which displays an indication of the respiratory rate on a

panel meter or other suitable display. An alarm circuit 42 is also activated if no breath is detected in an ajustable pre-selected time interval.

Calibration of the respiration monitor is achieved by simultaneously permitting the subject to breathe into any suitable spirometer or respirometer which will provide an indication of tidal volume, or into a bag of known volume, and adjusting the gain control to obtain an appropriate indication of tidal volume. This method has been found to be sufficiently accurate for clinical purposes and overcomes shortcomings in the prior art arrangements since it is fairly simple to perform.

An alternative form of garment 43 suitable for infants is shown in Figures 8 and 9. The construction of this garment is similar to that described above except that only four turns of wire are used for the coil 44. The garment 43 has additional Velcro fasteners 45 so that it may be joined under the crutch. The circuitry of the respiration monitor in this case is identical to that shown in Figure 6 from the phase locked loop 21 onwards. The rest of the circuitry up to and including the phase locked loop 21 is shown in Figure 10. The coil 44 or transducer and oscillator 46 are a separate unit powered by rechargeable batteries and attached to the garment 43. Since there is an oscillating signal in the coil 44 energy is radiated from the coil 44 at between 1.5 and 1.6 MHz, the frequency of the oscillator. This radiated signal is detected by an aerial 47 placed under a cot mattress on which the infant lies. The aerial 47 is composed of five rectangular loops of insulated copper wire measuring approximately 18 × 25 cm sandwiched between two sheets of flexible plastics material Any other configuration of aerial may also be suitable. The aerial 47 is connected to the remaining monitor circuitry by screened cable 48. The detected signal passes through an rf amplifier 49. The amplified signal is then applied to a mixer 50 where it is mixed with the output of a local oscillator 51, producing a beat frequency which is passed to the phase locked loop 21. An automatic gain control circuit 52 modulates the gain of the rf amplifier 49 to maintain a constant amplitude independent of the orientation of the coil 44 relative to the aerial 47.

A further circuit for a monitor suitable for use with infants is illustrated schematically in Figure 11, the part of the circuit up to and including the phase locked loop 53 being identical to that described with reference to Figure 10. In this embodiment, the phase locked loop circuit 53 converts the beat frequency into an analogue voltage which is passed to an AC coupled DC amplifier 54 with a time constant of about 10 msecs. The analogue signal then passes to a 5Hz low pass filter 55. The filtered signal is passed to a full wave rectifier 56 and then to a threshold detector 57. When the rectified voltage exceeds a pre-selected threshold limit the threshold detector 57 activates a reset circuit 58 which shortens the time constant of the AC coupled DC amplifier 54 to about 180 msec. The reset circuit 58 thus serves to restore the signal rapidly towards the baseline when it exceeds a pre-selected limit. The filtered signal can then be fed to a recorder 59 or display device as before.

The output from a 10Hz clock 60 is used to trigger a monostable 61 whose output is used to trigger a continuous sample hold 62. The signal from the 5Hz filter 55 is fed into the continuous sample hold 62 and also into one input of a comparator 63. The output 74 from the continuous sample hold 62, which lags behind the filtered signal, is fed into the other input of the comparator 63. When the filtered signal is falling from a peak to a trough it is more negative than the output 74 and the output of the comparator 63 is high. When the filtered signal passes the trough and starts rising towards the peak it becomes more positive than the output 74 and the output of the comparator 63 goes low. The output of the comparator 63 passes through a NAND gate 64, which inverts it, and this inverted signal is used to trigger a peak sample hold 67. When the output of the comparator 63 passes through a NAND gate 64 goes high (at each trough) the peak sample hold 67 starts to sample and continues to do so until the output of the NAND gate 64 foes low (at each peak) at which point it holds that voltage (the peak voltage) until the next trough occurs and the NAND gate 64 output goes high again. The signal from the NAND gate 64 also passes to a monostable 65 which gives an output pulse each time a trough occurs. This pulse then triggers a trough sample hold 66 which then holds the trough voltage. The outputs of the peak sample hold 64 and the trough sample hold 66 are passed respectively to the two inputs of a differential amplifier 68 and the resultant output, which represents the temporal change of the volume of air within the infant, is passed to a suitable display 69 such as a column of light emitting diodes giving an indication of the volume of each breath (tidal volume). A gain control is provided to adjust the output of the differential amplifier 68 for calibration purposes.

The output of monostable 65, which represents the commencement of each breath passes to two alarm circuits. An apnoea alarm 72 is activated if no breath is detected in an adjustable pre-selected time interval. A low breath alarm 70 is activated if seven successive breaths do not exceed a volume pre-selected by the level adjust 71.

These forms of monitoring offer the advantage that there are no wires to restrict or interfere with the movements of the subject. In addition where infants are being monitored to help prevent "cot-death", parents might be inhibited from handling their infants because of the presence of attached wires or tubing. The invention overcomes this reluctance which, if present, could adversely affect the psychological bond between a mother and her infant.

The respiration monitor may be modified by monitoring, in addition to the volumetric changes in the inductance coil, the relative phase of an upper turn of the coil around the thorax and a lower turn of the coil around the abdomen. During paradoxical breathing when the exterior wind tracts are blocked abdominal and thoracic movements become in anti-phase and thus when anti-phase movements are detected this may also be used to trigger an alarm.

Detailed circuit diagrams have not been given as the block diagrams described include known circuit arrangements. Variations in the respiration monitor from the arrangements described will be apparent to those skilled in the art while falling within the scope of the invention defined herein.

CLAIMS

1. A respiration monitor comprising an extensible coil for close encirclement about the body of a subject, the coil being wound in a plurality of turns with each turn being wound in the opposite sense to the preceding turn, and means for measuring changes in the inductance of the coil arising from the respiration of the subject.

2. A respiration monitor according to Claim 1 in which the coil is incorporated in a garment which can be opened along its entire length without breaking any electrical connection.

3. A respiration monitor according to Claim 2 in which the coil consists of a length of insulated wire incorporated in an elastic tape, the tape being attached to the garment as a single length in a series of alternating rows extending over the parts of the garment covering the thorax and abdomen.

4. A respiration monitor according to any preceding claim in which the coil forms an inductive element in a variable frequency oscillator.

5. A respiration monitor according to Claim 4 in which the oscillator is battery powered and attached to the garment, the coil acting as a radiative element to transmit energy from the oscillator, the respiration monitor incorporating a receiving aerial for detecting the energy transmitted from the coil.

6. A respiration monitor according to any preceding claim incorporating an alarm signal adapted to operate when any desired parameter of the respiration reaches a pre-selected level.

7. A respiration monitor incorporating a garment substantially as described with reference to Figures 3 and 4 or 8 and 9.

8. A respiration monitor, substantially as described with reference to Figures 6, 10 or 11.

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